# Kinematic GPS surveys in support of the Shuttle Radar Topography Mission (SRTM)

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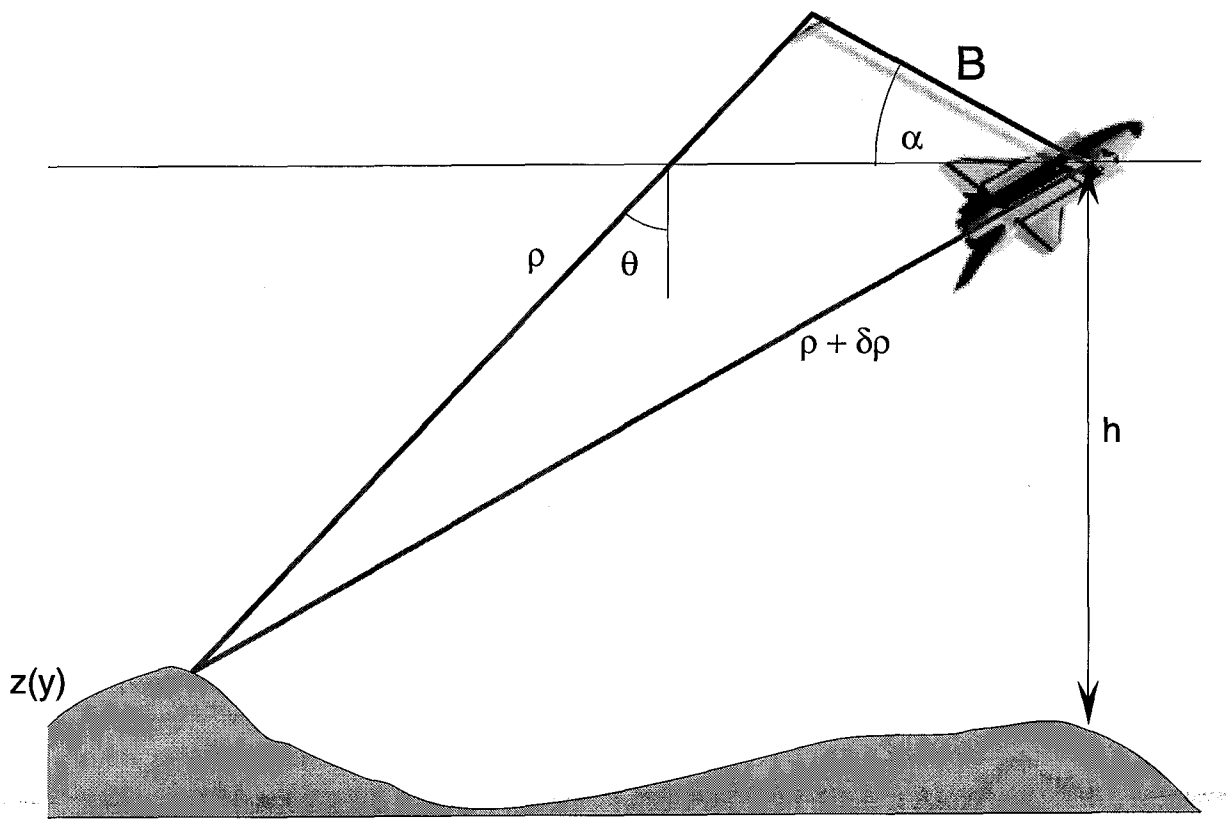
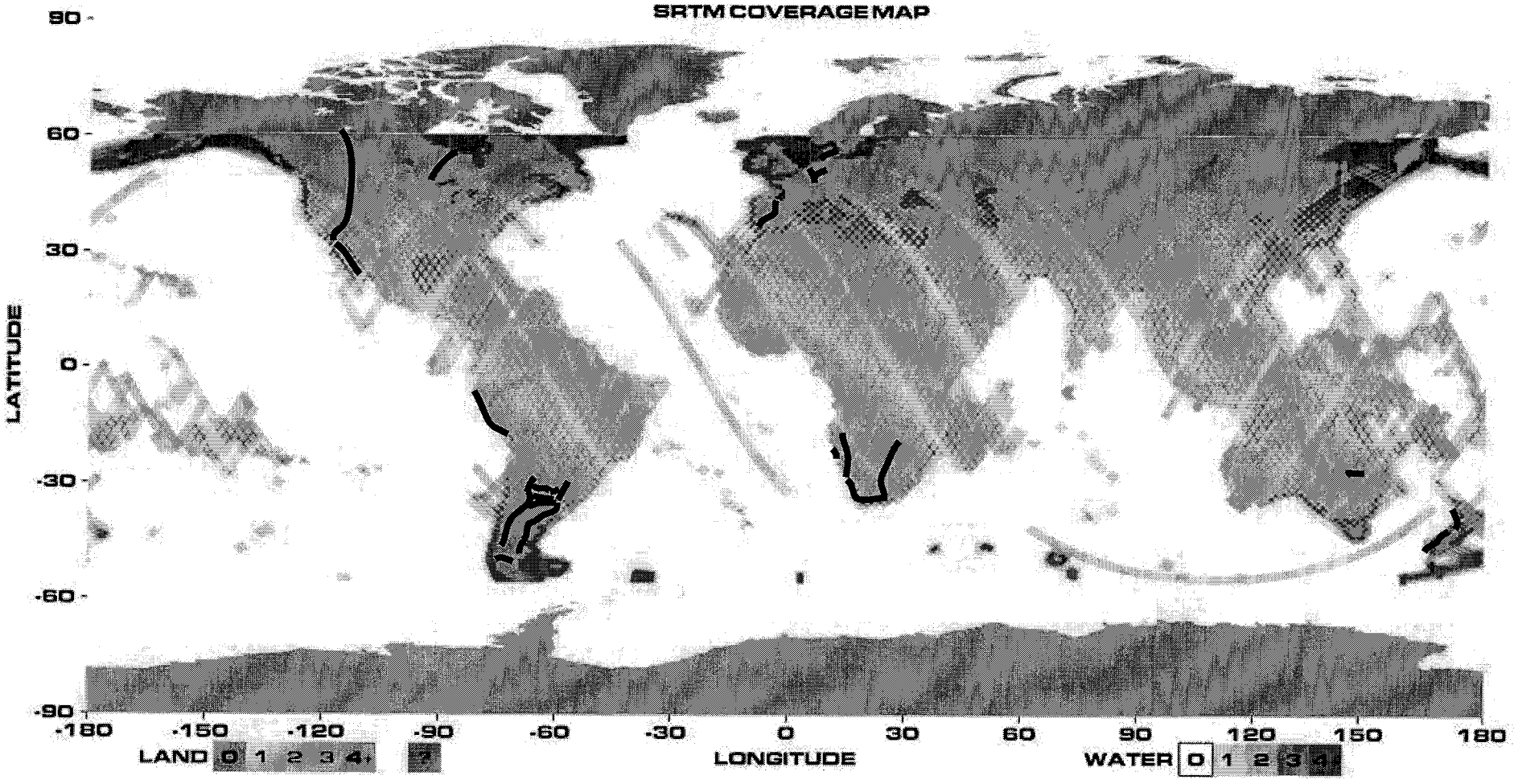
## SRTM Kinematic Ground Surveys

### Background

- IFSAR systematic errors have long spatial and temporal wavelengths
- High accuracy (~ 1m) height measurements required for height calibration
- Available DEMs with the required accuracy are too sparse
- Kinematic GPS data may be used for calibration, verification, and generation of mosaic ground control points



# SRTM Ground Coverage




Black lines indicate areas of JPL processed ground surveys

## Data collection

- Continental Scale Transects
- More than 60,000 km of road surveys including "crossing" during the surveys
- Organized by NIMA with host country support

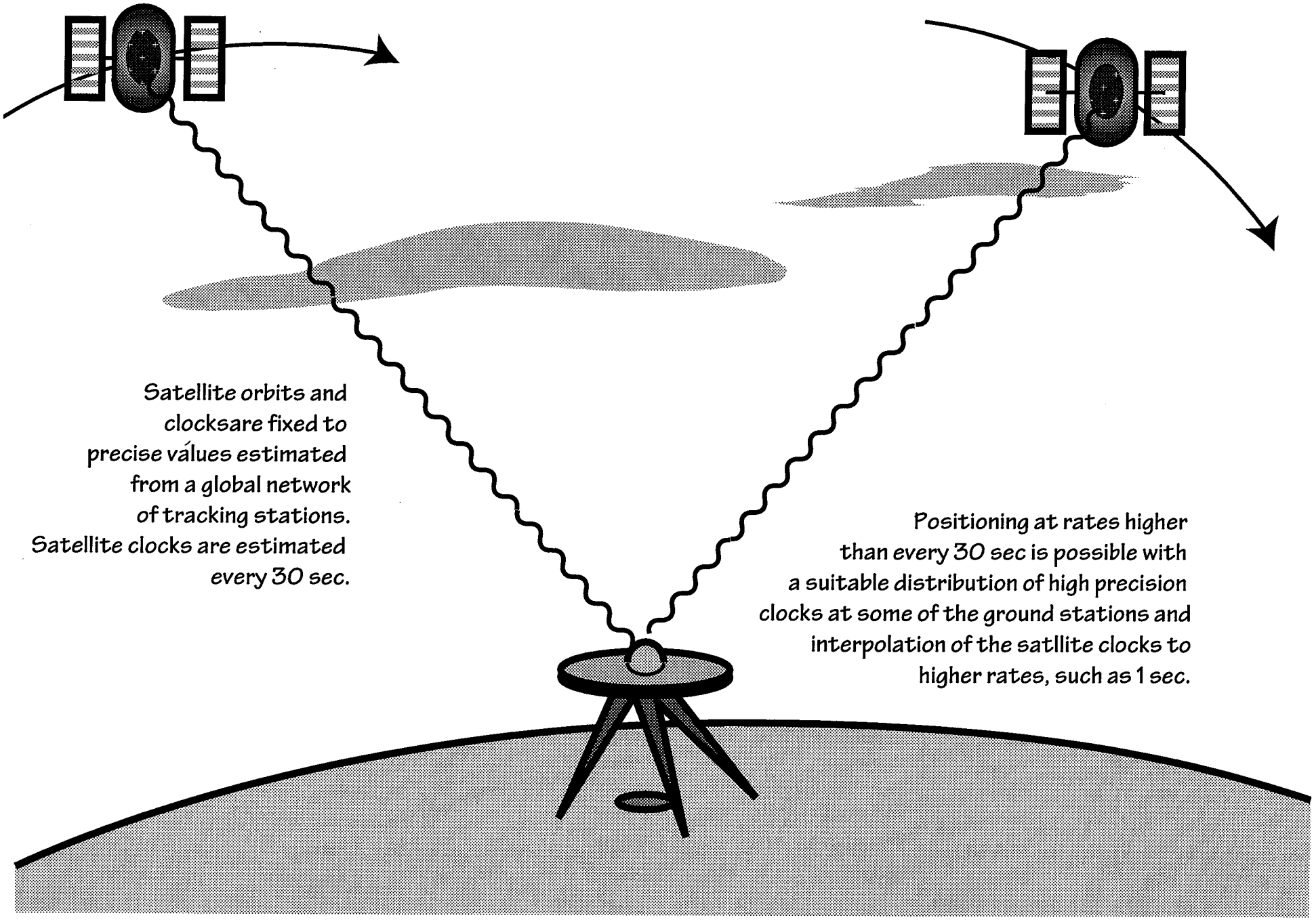
## Data Processing

- GIPSY Software
- Precise Point Positioning
- Analysis at NIMA and at JPL and Raytheon
- JPL IGS Orbits and High Rate Clocks

## Data processed at JPL

| | |
|---|---|
| **North America** | |
| Canada | 10/98 |
| Mexico | 5/99 |
| United States | 8/97 |
| **South America** | |
| Argentina | 2/98-4/98 |
| Peru | 4/98-6/98 |
| **Europe** | |
| Denmark | 8/99 |
| Germany | 4/99 |
| Spain | 9/99-11/99 |
| **Africa** | |
| Namibia | 4/99-5/99 |
| South Africa | 5/99-6/99 |
| **Oceana** | |
| New Zealand | 4/98 |

# Precise Point Positioning



Satellite orbits and clocksare fixed to precise values estimated from a global network of tracking stations. Satellite clocks are estimated every 30 sec.

Positioning at rates higher than every 30 sec is possible with a suitable distribution of high precision clocks at some of the ground stations and interpolation of the satllite clocks to higher rates, such as 1 sec.

## Survey Data Analysis

**Precise Point Position of single receiver data using**

- **GIPSY software**
- **JPL/FLINN IGS Orbits and 30 sec. high rate clocks**

  (`ftp://sideshow.jpl.nasa.gov/oub/gipsy_products/hrclocks`).

**Process GPS carrier phase and pseudorange data using an undifferenced model fixing, in the model, the satellite positions and the satellite clocks to values previously estimated from a global network.**

**Processing data with Precise Point Positioning allows for efficient collection of the survey data since it does not require local base stations for differencing.**

**Interpolate 30 sec clocks to 1 sec sampling rate of receivers. Since all data were collected with Selective Availability (SA) on, this interpolation incurs a range error of 7 cm.**

## Processing Summary

### The following table shows a summary of the number of receivers, files, days dynamic segments, static surveys, etc. by region surveyed.

| Region | Distinct Receivers | RINEX Files | Distinct Days | 1-Day Files | Dynamic Segments | Static Surveys | Dynamic Revisits | Number of Points |
|---|---|---|---|---|---|---|---|---|
| Argentina | 4 | 40 | 15 | 52 | 506 | 226 | 200 | 553815 |
| Denmark | 7 | 11 | 3 | 11 | 78 | 52 | 99 | 72902 |
| Germany | 26 | 77 | 9 | 77 | 32 | 82 | 4 | 105265 |
| LA2Hay | 5 | 30 | 12 | 39 | 187 | 72 | 160 | 249562 |
| Manitoba | 9 | 31 | 10 | 36 | 174 | 283 | 452 | 352243 |
| Mexico | 16 | 89 | 20 | 101 | 209 | 197 | 138 | 274520 |
| NZ_North | 5 | 28 | 9 | 43 | 355 | 369 | 674 | 326785 |
| NZ_South | 3 | 22 | 10 | 38 | 159 | 148 | 85 | 142149 |
| Namibia | 3 | 43 | 15 | 42 | 305 | 297 | 624 | 454960 |
| Peru | 8 | 36 | 12 | 42 | 207 | 138 | 110 | 187497 |
| S_Africa | 5 | 64 | 22 | 66 | 606 | 470 | 1130 | 677958 |
| Spain | 15 | 210 | 22 | 210 | 313 | 597 | 237 | 495357 |
| Total | 106 | 681 | 159 | 757 | 3128 | 2931 | 3994 | 3891821 |

## Validation

**The high rate clocks, orbits, and analysis strategy were validated by**

**Applying the kinemtaic processing strategy to 30-second data from one IGS station close to the surveyed area and comparing the coordinates with the ITRF97 position of the station. Horizontal agreement with ITRF was on the order of a few cm RMS and vertical agreement was biased upward by a few decimeters with an RMS of 10-20 cm.**

| Station | North (cm) | East (cm) | Height (cm) |
|---|---|---|---|
| ALGO | 6.1 | -1.9 | 24.6 |
| AREQ | -5.0 | 1.2 | 30.8 |
| AUCK | -6.3 | 1.6 | 64.4 |
| AUCK | -6.3 | -0.7 | 43.9 |
| GOL2 | 4.2 | -1.0 | 34.5 |
| GOL2 | 6.3 | -0.5 | 6.7 |
| HRAO | -8.2 | -2.9 | 18.1 |
| HRAO | -9.2 | -2.8 | 43.0 |
| LPGS | -8.7 | 5.1 | 13.6 |
| MAD2 | 3.4 | 4.2 | 29.5 |
| POTS | 9.4 | 0.2 | 49.5 |
| WTZR | 4.6 | -1.3 | 24.0 |
| Mean | -0.8 +/- 7.0 | 0.1 +/- 2.5 | 31.9 +/- 16.3 |

When quality high rate (30 sec.) clock solutions were not avaialble, new high rate clocks were generated from a regional distribution of IGS stations.

The kinematic survey solutions were divided into dynamic and static segments with 60 or more points

The repeatability of static surveys were checked at the sampling rate (typically 1 sec) rate and at the high rate clock rate of 30 seconds

Revisits show the actual repeatability that can be obtained with the kinematic processing strategy. Typically there are three kinds of revisits:

1. Two receivers and antennas installed in the same truck and tracking simultaneously

2. The same receiver/antennas retracing the same road, sometimes in a different direction or lane

3. Two different receivers tracing the same road at different times

Results from these static and kinematic revisits are consistent with the results from applying the kinematic strategy to fixed stations.

## Example of the use of Precise Point Positioning for Kinematic GPS Surveying

**Australia Survey**

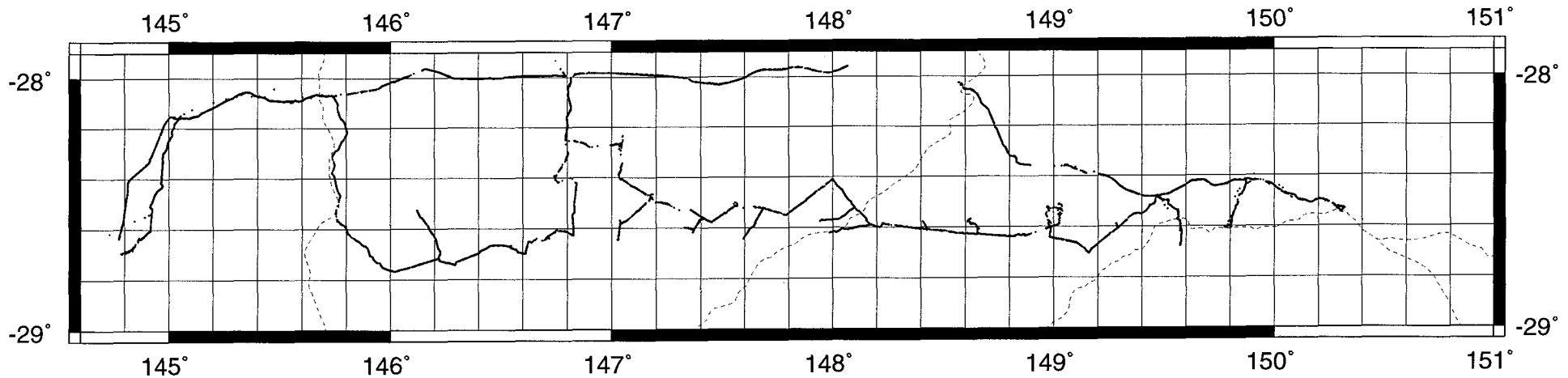
- Nov. 6 - 10, 1996
- Calibration and verfication of TOPSAR DEM with 1 m height error

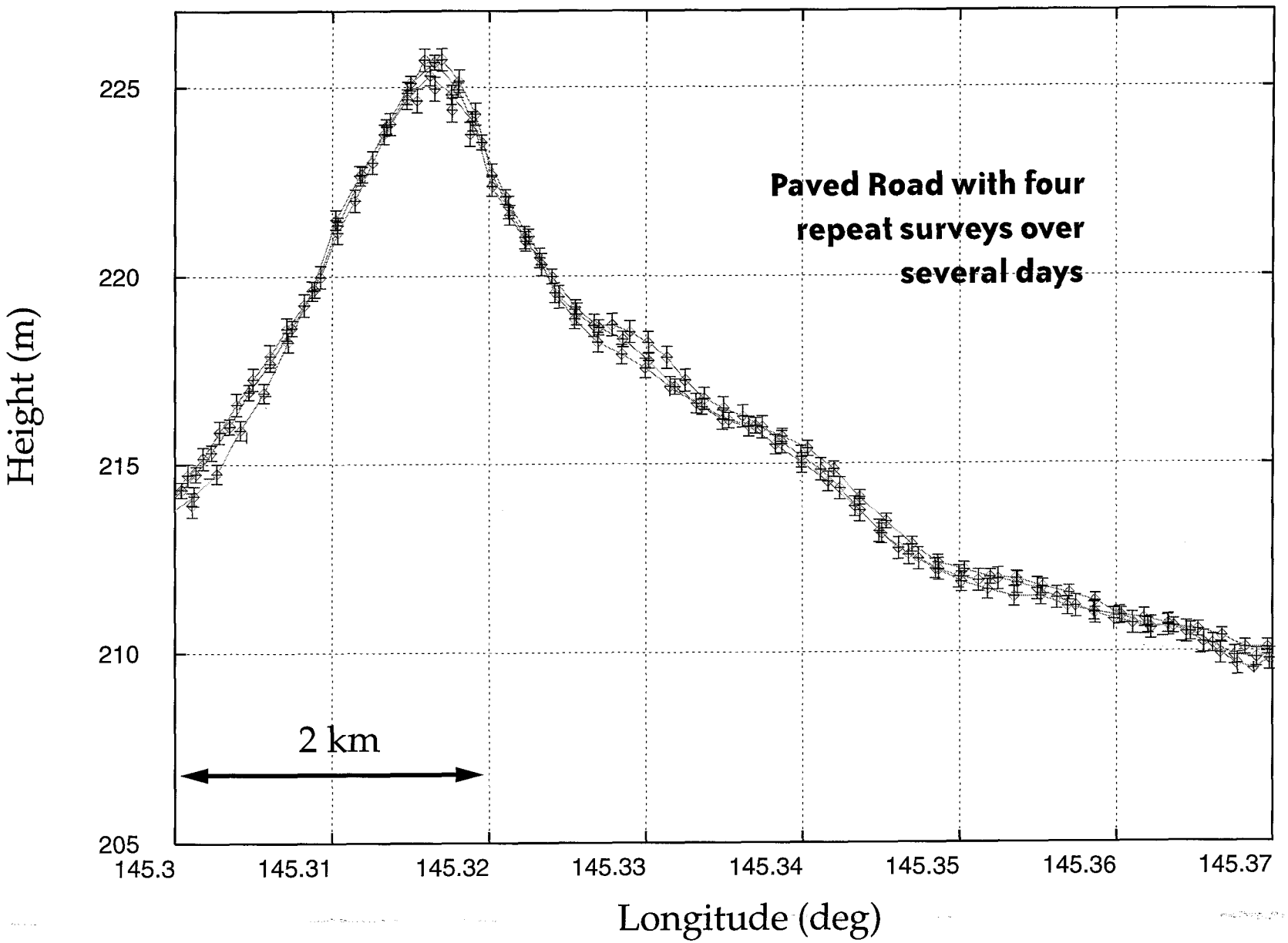
**Technique**

- One 8 channel GPS receiver
- 2 drivers
- 3000 km of paved and unpaved road
- 1 sec sample rate
- Precise Point Positioning
- High-rate clocks

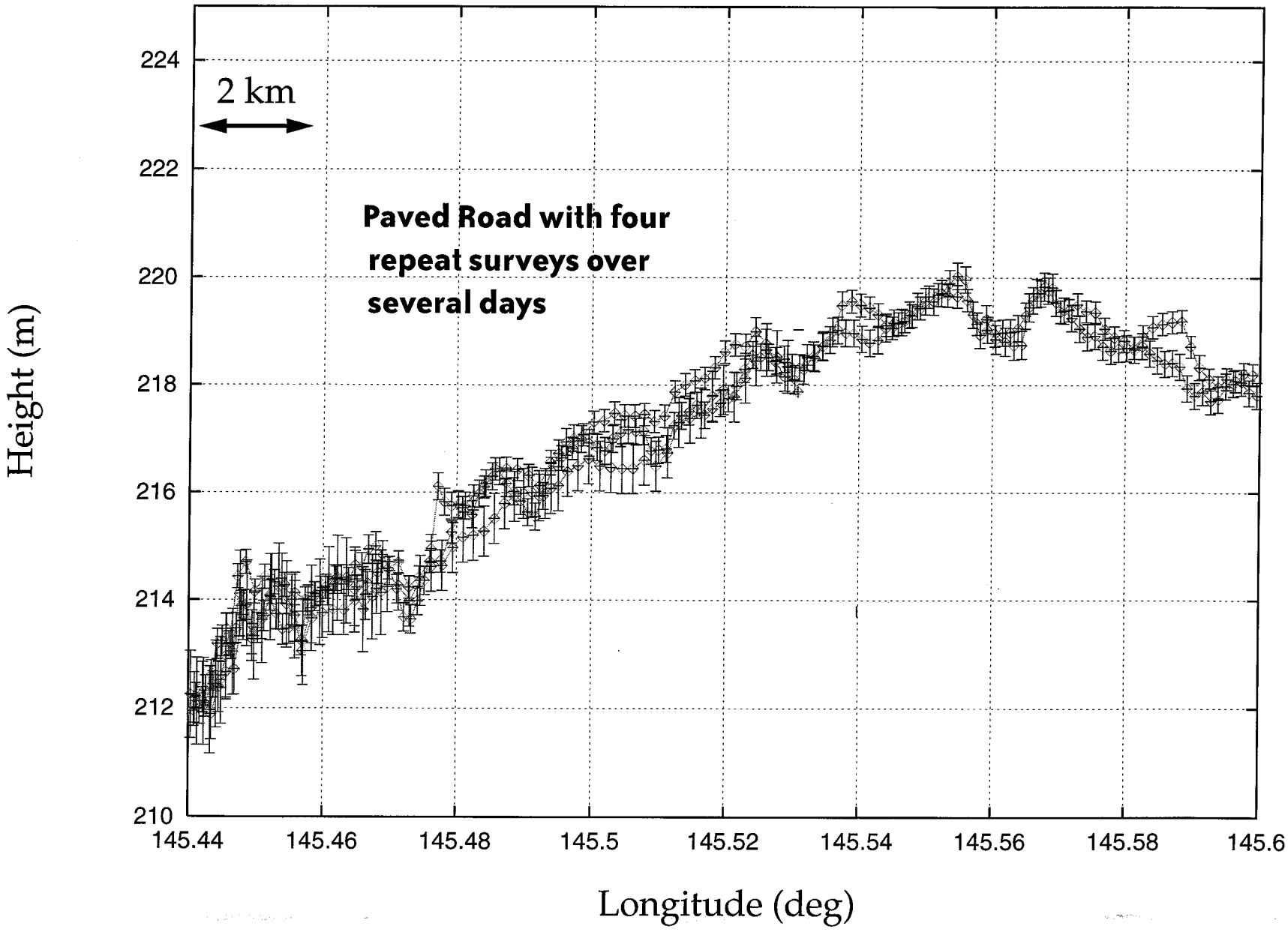
**Problems**

- Data collection is hampered in areas of trees, high relief, and urbanization
- Signal Blockage
- RFI




Cunnamulla to Eulo
Paved Road with four repeat surveys over several days
2 km
Height (m)
225
220
215
210
205
145.3
145.31
145.32
145.33
145.34
145.35
145.36
145.37
Longitude (deg)

# Cunnamulla to Eulo



## Results

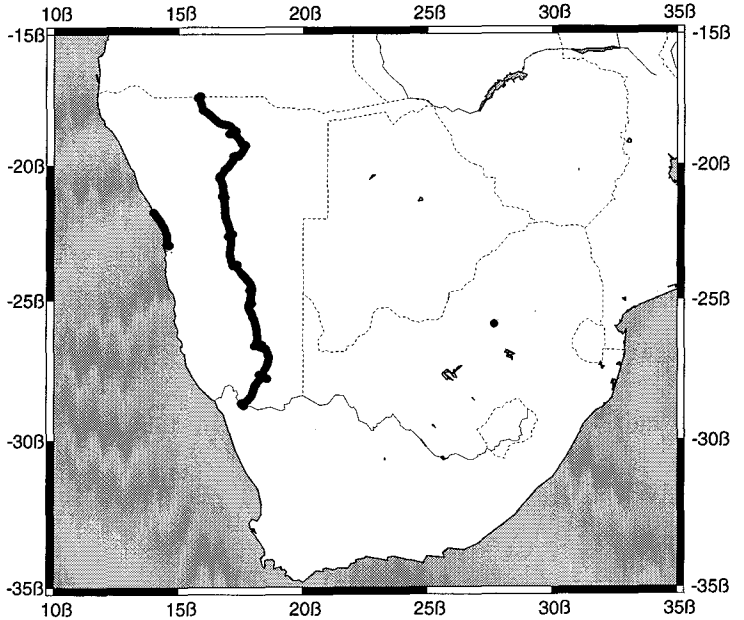
Using JPL precise orbits and high-rate clock products, the data were decimated to 5 sec points and processed using GIPSY.

## Statistics

RMS position errors in cm for several locations in Australia with respect to a polynomical fit to a segment of the road.

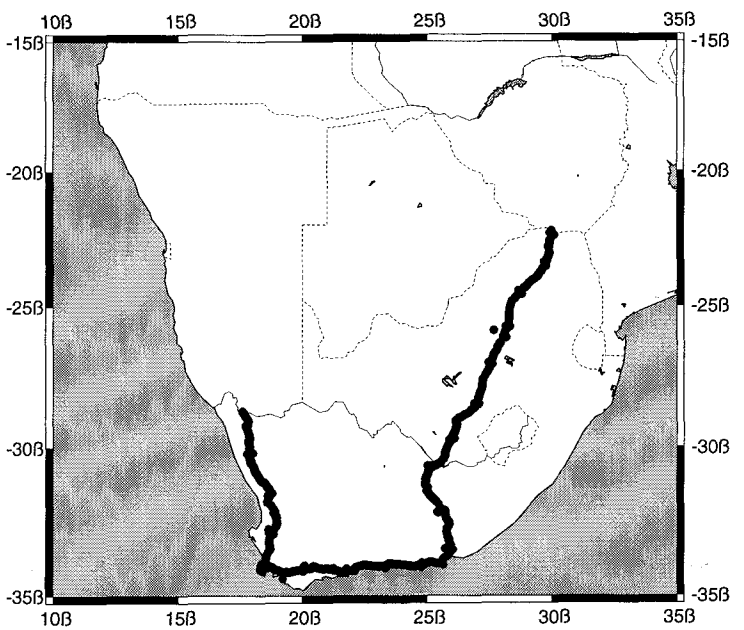
| | No. of points | North | East | Vertical | Driving condition |
|---|---|---|---|---|---|
| cattle | 422 | n/a | n/a | 28.5 | dirt road |
| Eulo | 9 | n/a | n/a | 4.3 | paved road |
| Corner2 | 17 | n/a | n/a | 22.8 | paved road |
| Eulo2 | 37 | n/a | n/a | 37.0 | paved road |
| Flat tire | 909 | 8.2 | 4.7 | 15.2 | stationary |
| Lunch | 938 | 7.3 | 9.1 | 14.5 | stationary |
| (JPLM | 17000 | 9.2 | 7.0 | 20.6 | static test) |

## Namibia



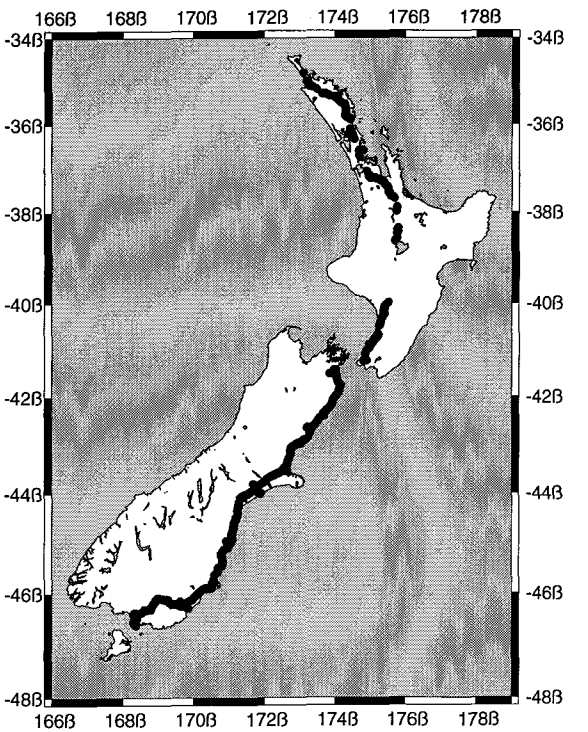

GMT Jun 22 15:36 Namibia

## South Africa



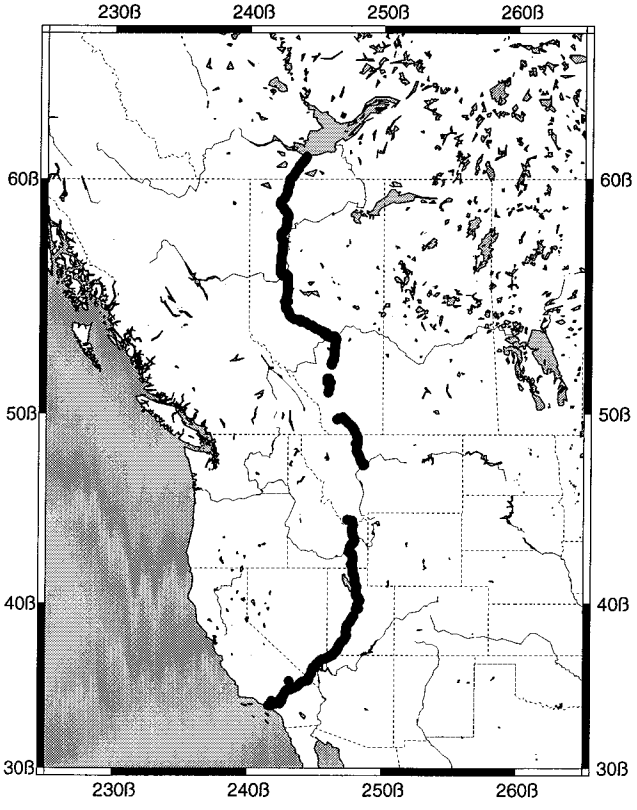

GMT Jun 22 15:40 South Africa

## New Zealand



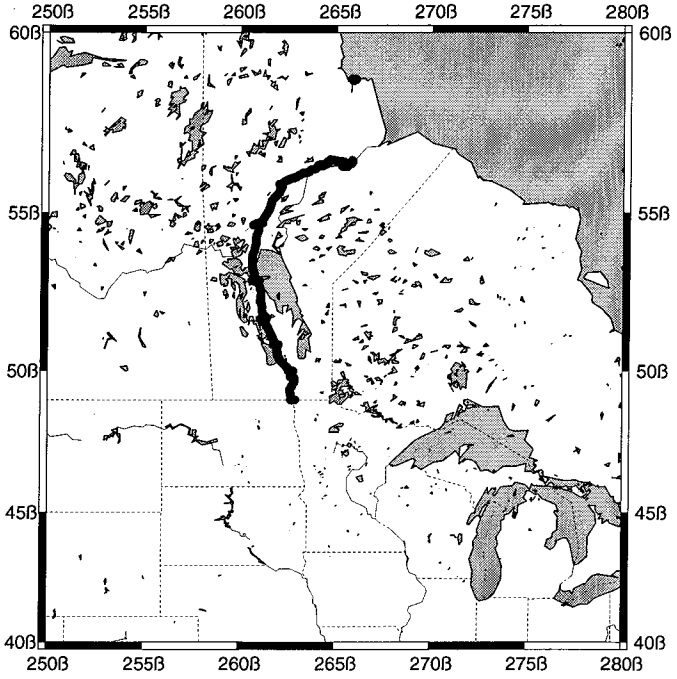

GMT Sep 18 14:37 New Zealand - South Island

## United States



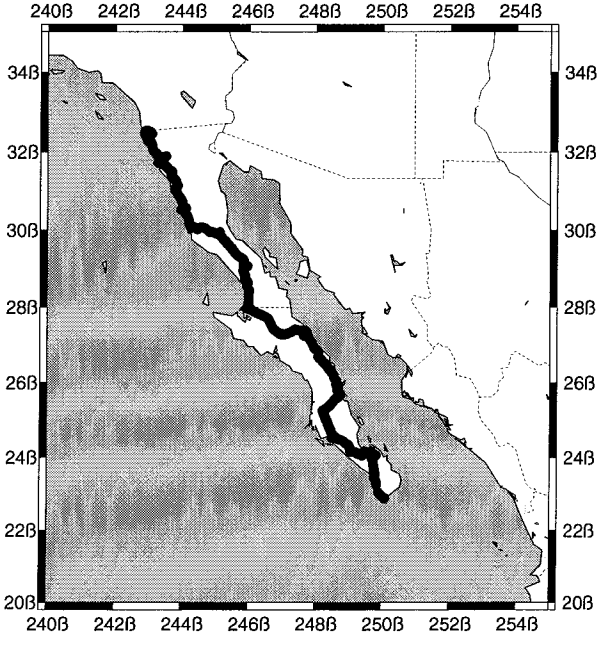

GMT Jun 22 15:29 LA to Hay River

## Canada



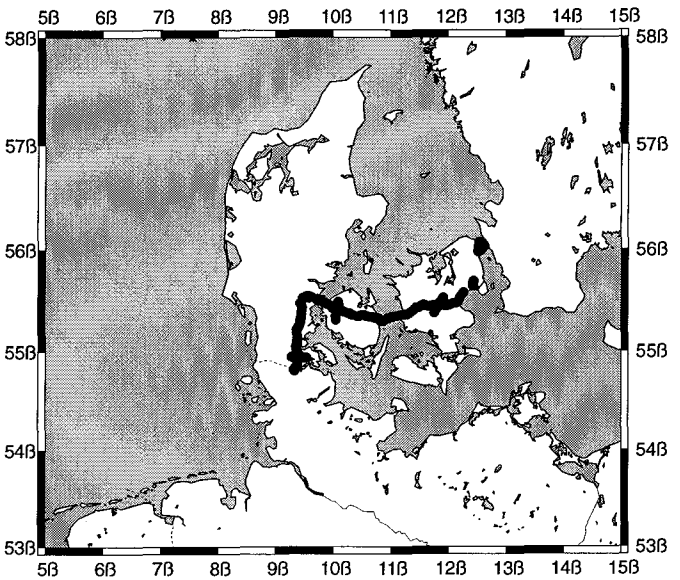

GMT Jun 27 14:01 Manitoba, Canada

## Mexico



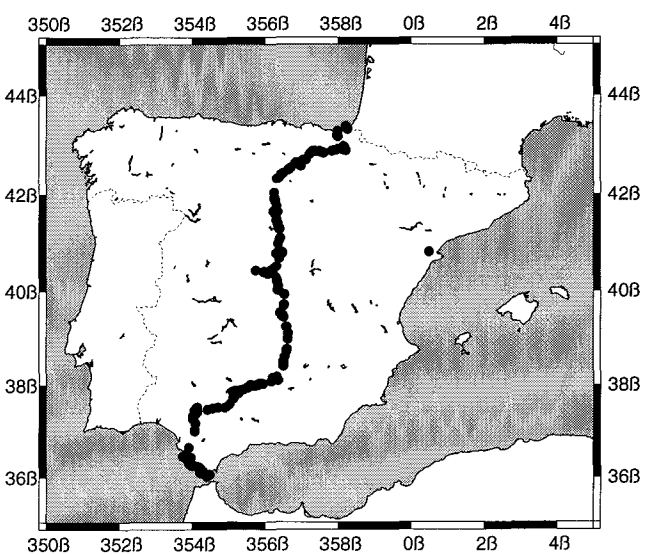

GMT Aug 11 14:32 Mexico

## Denmark



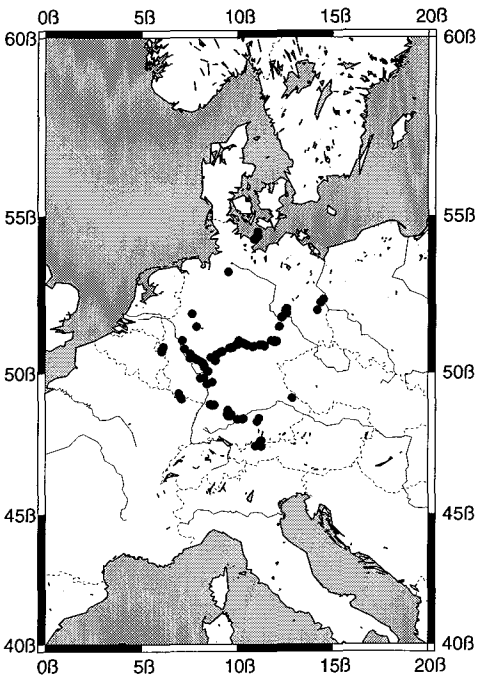

GMT Sep 18 14:33 Denmark

## Spain



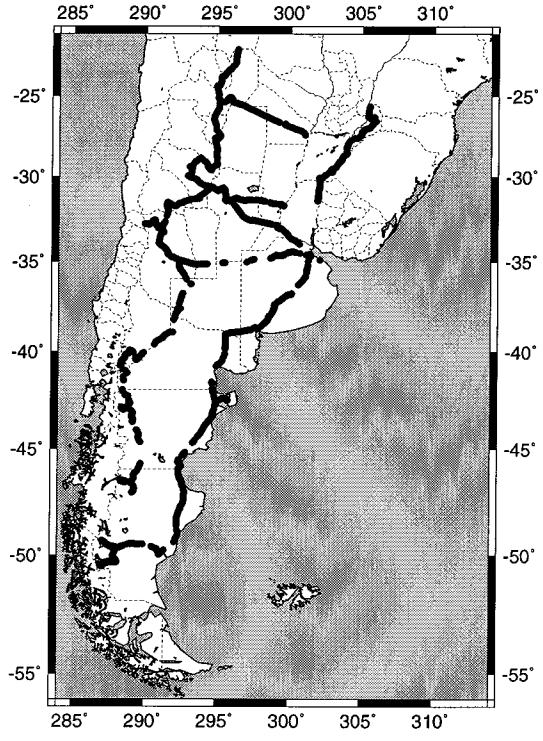

GMT Sep 18 14:38 Spain

## Germany



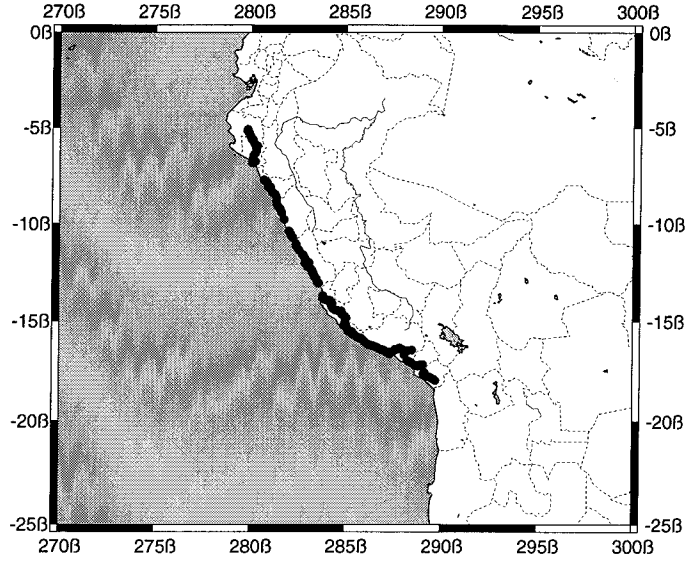

GMT Jun 22 15:28 Germany

## Argentina




GMT Jun 27 14:07 Argentina

## Peru




GMT Jun 22 15:37 Peru

## Summary

Kinematic GPS surveys in support of the Shuttle Radar Topography Mission (SRTM) are being conducted in several regions of the world

Processing of the GPS data is being done using precise point positioning with GIPSY and JPL precise orbits and high-rate clock products

Precise point positioning allows surveys to be conducted using the existing IGS infrastructure and data products without the need for deploying GPS base stations

Surveys provide ~30 cm height error for calibration and verification of SRTM DEM

Improved (reduced) height error could be achieved with more frequent high rate clocks and bias fixing